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Review of abalone culture and research in New Zealand

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Abstract

Despite interest and research in abalone aquaculture since the 1970s, the abalone farming industry is still in a nascent stage in New Zealand. The current aquaculture industry is based on mussels, salmon and rock oysters, and only trial marketing of cultured abalone has been done. The research on abalone in New Zealand reflects a young industry, with the largest category of published papers since 1990 on spawning and settlement. The status of the industry and research related to solving critical problems are reviewed. The major areas requiring more research are in overall system development and integration with food and stocking densities, food development both for recent settlers and later stages to achieve greater growth rates and lower variability among abalone, and algal harvesting effects and techniques to provide the information necessary for more harvesting permits to be granted. The industry will have to be increasingly focused on marketing and product development.

Key words: Abalone, *Haliotis*, aquaculture, New Zealand, Review

Introduction

As in most countries with a history of abalone fisheries there is considerable and increasing interest in abalone aquaculture in New Zealand. The reasons for this broadening of the production base from capture fisheries to farming have been discussed or mentioned in many publications and relate generally to market awareness and demand, coupled with occasional management problems and limits to the wild catch (Shepherd *et al.* 1992, Fleming and Hone 1996). In terms of research, there has been a change in emphasis during the past seven years. Fleming and Hone (1996) pointed out that 25% of papers presented at the First International Symposium on Abalone in 1989 related to abalone culture, whereas 50% of papers related to this topic at the second symposium in 1994. While this is not necessarily an accurate reflection of the overall research effort on abalone worldwide, there has clearly been more research published recently on abalone culture from a wide range of countries. The papers from the Second International Symposium on Abalone show there are common themes that encompass abalone research but also many factors unique to each country. This paper discusses some of these themes relating to abalone aquaculture and suggests how research in New Zealand can help the nascent industry and where it fails to solve industry problems.

The primary premise of this review is that the main purpose of aquaculture is to make money. The corollary of this is that all research should be directed primarily at solving specific problems that hinder the industry in development and production. This is especially important where research dollars are few and a form of funding triage occurs: the most needy problems should be identified and solved first. Four arguments are the focus of this review: 1) that research into abalone culture should have as a major component an assessment of the costs associated with developing techniques;

2) that research should be aimed at specific problems impeding progress in establishing viable aquaculture enterprises; 3) that the scale of experimental research and development should be appropriate to a commercial scale; and 4) that research should be appropriable by industry.

Background to abalone research in New Zealand

Three categories of background information are relevant to understanding the environment for abalone research in New Zealand. First, the abalone catch from the natural fishery has been relatively stable at around 1200t per year for the past decade (Schiel 1992a). There is considerable knowledge about the biology and ecology of the main fished species, *Haliotis iris* Martyn (1784), including feeding and movement (Poore 1972a, b), growth and mortality (Poore 1972c, Sainsbury 1982), morphological variation both locally and geographically (McShane *et al.* 1994a), reproduction (Poore 1973, Wilson and Schiel 1995, Hooker and Creese 1995), and fine-scale distribution (McShane *et al.* 1994b, McShane 1995). There has been considerably less research on the other two New Zealand haliotids, *H. australis* Gmelin (1791) and *H. virginea* Gmelin (1791).

Second, the aquaculture industry is not large in New Zealand and is based on only a few species (Table 1). There are 65,000t of the green-shell mussel *Perna canaliculus* produced annually on long-lines, of which 21,000t is exported with a value of NZ$87 million. Salmon, almost all of which is chinook (*Oncorhyncus tshwaytscha*) grown in sea-cages, has a total annual production of 6,500t, of which 5,000t is exported with a value of $34 million. Around 4,800t of the Pacific oyster *Crassostrea gigas* are grown annually, of which 1,436t is exported. Although there has been considerable discussion about aquaculture in New Zealand, and the pros and cons of indigenous species have been analyzed (Hayden 1988), little has translated into production. The aquaculture of paua has been discussed and researched for at least 18 years but, to my knowledge, only trial marketing of products and a small trade in production of larvae and juveniles have occurred.

Third, there are few sources of funds for aquacultural research in New Zealand. The Foundation for Research, Science and Technology (FoRST) provides most of the funding for all institutional research through its Public Good Science Fund. One output area is Fisheries and Aquaculture Industries, which has an allocation of $6.5 million (1996–97 figures), of which $1.5 million was specifically allocated for aquaculture production in 1996–97 (Anonymous 1996b). A few aquaculture research programmes are funded by industry, mostly with matching funds from a scheme administered by FoRST. Altogether, paua research has around 22% of the FoRST aquaculture funding, with projects on larval settlement and enhancement of natural populations, while industry contributes to others relating to food, algal harvesting, system development and pearl growth.

There has been a considerable amount of work on spawning, culture and rearing of paua since the late 1970s and there is continuing enthusiasm shown by prospective industry participants in attending hands-on workshops in paua culture. Given this work and interest over many years, it seems reasonable to ask what has resulted from this effort, interest and expenditure. Why is there not

Table 1 Aquaculture production in New Zealand for 1995, including export tonnage, value, and total production (domestic + export). Source of export figures: New Zealand Fishing Industry Board (Anonymous 1996a); salmon figures from N. Boustead (National Institute of Water and Atmospheric Research, pers. comm.). NZ$1 = US$0.70 (at November 1996).

Species	1995 export figures		Total
	t	$(million)	t
Oysters (*Crassostrea gigas*)	1,436	11	4,800
Salmon (mostly *Oncorhynchus tschawytscha*)[1]	5,061	34	6,500
Mussels (*Perna canaliculus*)	21,258	87	65,000

[1] Sockeye salmon (*O. nerka*) have a total aquaculture production of 10–20 t annually

more than an incipient industry in New Zealand? Has the research been appropriate for the production of paua and development and expansion of the industry, or are there other factors primarily responsible for what can be seen as slow progress?

Research into paua culture

As evidenced by the papers published from the Second International Symposium on Abalone, six major topics encompass most of the research effort in abalone culture internationally (Table 2). Artificial diets and nutrition have assumed considerable importance in the past few years, primarily because of the need for high quality foods that are predictably available. Various aspects of husbandry, including the use of growth hormones (Taylor *et al.* 1996) and anaesthetics (White *et al.* 1996) were presented, while there were two papers on system design. The problems and opportunities of marketing were discussed in one paper (Oakes and Ponte 1996). New Zealand research on paua produced 25 publications since 1990, 64% of which were related to fisheries and 36% to aquaculture (Table 2B). In comparing the subjects of the 11 aquaculture papers to the spread of topics internationally, only one was on diet and nutrition (Stuart and Brown 1994). The major categories for New Zealand research were spawning and settlement (36%; Moss and Tong 1992a, b, Moss *et al.* 1995, Moss In Press), enhancement of natural populations using hatchery-raised paua (18%; Schiel 1992b, 1993), and analysis of stress on paua due to handling and shipping (18%; Baldwin *et al.* 1992, Wells and Baldwin 1995). Other categories were system design and techniques (Tong and Moss 1992), and genetics relating to hatchery production (Smith and Conroy 1992). It therefore appears that the research effort in New Zealand has a different focus from research in other countries. Does this reflect different problems in New Zealand, a different stage of development of the industry, or something else? To answer these questions I categorise the problems in New Zealand paua farming and outline what is known. Almost all of this relates to *Haliotis iris*, although some interest in other species is developing (*e.g.*, Moss 1997).

Techniques for spawning and settling

The techniques for spawning paua are straightforward and routine, and similar to those used elsewhere (Hahn 1989, Tong and Moss 1992). In both *Haliotis iris* and *H. australis* gonads are at

Table 2 The number and percentage of papers published on selected aquaculture topics, A. from the Second International Symposium on Abalone 1994 (from Aquaculture 140, 1996), and B. since 1990 from abalone research in New Zealand.

A. From Second International Symposium on Abalone, 1994

Topic	Papers	%
Artificial diets and nutrition	8	50
Post larval culture	1	6
Husbandry	3	19
Tropical abalone	1	6
System design	2	12
Marketing	1	6

B. From New Zealand research since 1990

Topic	Papers	%
Diet and nutrition	1	9
Handling stress	2	18
Spawning/settlement	4	36
System design/techniques	1	9
Enhancement	2	18
Genetics	1	9

their smallest during late summer (Feb – Mar), although there is considerable local and regional variation (Poore 1973, Wilson and Schiel 1995, Hooker and Creese 1995). Paua can usually be spawned in all but the warmest summer months. Settlement is usually done on diatom-covered panels, without the use of GABA (c.f. Morse 1992). The techniques used throughout New Zealand are mostly those contained in a technical report (Tong *et al.* 1992), which is used in workshops for training potential farmers in paua culture.

Early settler survival and growth

The growth and survival of post-settlement larvae are variable, with occasional high mortalities (>90%) reported at around 3 weeks (L Tong, National Institute of Water and Atmospheric Research, pers. comm.) when paua are *c.* 700μm long and their radulae are developing more lateral teeth. High mortality may, therefore, be associated with a change in food requirements, the provision of which may depend on the mixture of available diatoms. Another factor may be oxygen depletion in the boundary layer on the surface where post-larvae grow (Searcy-Bernal 1996). Specially formulated artificial foods (*e.g.*, Knauer *et al.* 1996), or the provision of specific diatom cultures, may help reduce variability in survival and growth at this stage of development. A major programme funded by FoRST, attracting $182,000 annually (Anonymous 1996b), deals mostly with these early stages of post-larval survival and growth.

Despite the unknowns and the occasional problems with post-larval survival, it seems unlikely that this is a major impediment to the development of the paua farming industry at this stage. While variable early survival has a real cost, it is probably not great overall. Furthermore, hatcheries have been able to produce the numbers of juveniles required by industry so far. The problem of post-larval survival may become more important as industry expands and requires vast numbers of juveniles for year-round production. This will entail having an optimal mixture of food and conditions for all phases of juvenile growth, allowing predictable costings and cash flow in hatchery production.

Table 3 Current paua farming ventures in New Zealand (data supplied by R. Beattie, New Zealand Abalone Farmer's Association, October 1996).

A.	Geographic spread	
	Region	**Number of farms**
	Auckland/Northland	1
	Taranaki	2
	Canterbury	2
	Otago	1
	Stewart Island	2
B.	Types of system used	
	Type	**Number of farms**
	V-tanks	3
	High-sided, narrow tanks	1
	Stacked, flow-through	1
	Barrel culture	1
	Unknown/Undecided	2
C.	Species used	
	Species	**Number of farms**
	Haliotis iris	7
	Haliotis australis	1
	H. iris and *H. australis*	1

Food/diet/nutrition requirements

Paua are weaned from diatoms onto macroalgae at around 5mm shell length. In terms of natural food, a mixed diet of several species of brown and red seaweeds seems to produce the best growth of *Haliotis iris* (Wilson 1987, Stuart and Brown 1994). Artificial foods made in New Zealand and elsewhere are available and are used in at least two industry facilities. One major problem with food and nutrition in New Zealand, however, is that there are few published and, therefore, appraisable research results on the effects of different diets on long term growth of juveniles to marketable sizes. There is no published research on the nutritional requirements of paua. Furthermore, provision of the large quantities of natural seaweeds necessary for a commercial facility requires an algal harvesting permit, few of which have been granted so far.

Food is a major cost in any production facility. Artificial food may currently be too expensive for economic viability (Fleming *et al.* 1996) and the costs of gathering, transporting and feeding natural seaweeds on a commercial scale are largely unknown.

Husbandry/tanks/systems

Several systems of rearing paua are used in New Zealand. The V-tanks advocated in instructional courses (Tong and Moss 1992, Tong *et al.* 1992) have the advantages of a large surface area, easy access for feeding and cleaning, and availability. One disadvantage is that sorting and removing paua can be back-breaking work. Vertically stacked, round tanks are planned for at least one facility, while at least one other uses narrow, high, rectangular tanks. Coupled with tank design is the type of water system used. In southern New Zealand, for example, where water temperatures range from around 7 – 17°C, there may be advantages in heating water during the coldest winter months. Unpublished research indicates that paua feeding is severely reduced below 10°C, whereas paua will continue to feed and grow when the temperature is maintained above 15°C (Schiel unpublished, *c.f.*, Nie *et al.* 1996). Each of these systems has its own characteristics of water flow, air supply, and methods of feeding and handling paua.

Regulatory procedures

New Zealand has many regulations relevant to the aquaculture industry. These involve local, regional and national considerations, especially in compliance with the Resource Management Act (1991) which requires impact assessments for commercial development of land and use of natural resources. In a land-based facility, permits are required for land use (*i.e.*, compliance with local and regional plans), water intake and water discharge. The effects of the discharge need to be detailed, and modification and on-going monitoring may be required. A freshwater farming permit is required to hold animals for land-based aquaculture, and a marine farm license is needed for sea-based operations (such as barrel farming; *c.f.*, Aviles and Shepherd 1996). To buy and sell paua, a fish receiver license is required. If natural seaweeds are used as food, an algal harvesting permit must be held.

The costs in time and money in obtaining all of the necessary permits can be high, especially if there are objections and proceedings are drawn out. While the procedures may be expensive and administratively cumbersome, the regulatory requirements by themselves are probably not an impediment to industry progress at this stage.

Marketing/product development

In New Zealand at least, it is not yet clear what the market is for cultured paua. There has been much talk about "cocktail-sized" paua (around 70mm shell length) but no clear markets have yet been established. There is also considerable interest in paua "pearls", mostly blister pearls (or mabe) grown on the inside of shells. To date, however, the incipient industry has not been market-driven, and many argue that this has been the major reason for such slow progress in the development of the paua farming industry.

Investment

Potential investors have been wary about aquaculture since the late 1980s, when it became clear that the hype surrounding the industry was not producing quick results. There are high start-up costs in land, plant, materials, and permits, and there is no clearly established market for mass-produced small paua. There is a long lead time to produce even moderate cash flow, and a longer time for real profits. No single system of plant, feeding and techniques is readily available to give a reasonable degree of predictability about production and costs. Many of these problems have not been resolved sufficiently to attract investors.

In many ways, there are striking parallels between the paua culture industry today and the mussel (*Perna canaliculus*) industry in its early stages of development in the 1970s. Most investors are individuals or small companies, often beginning with inadequate longer term finance. As in the early mussel industry (Meredyth-Young and Waugh 1985) many types of production systems are used and markets are not clearly defined. It was not until more standardized equipment and procedures were developed, coupled with the involvement of larger fishing companies in terms of finance, processing plants and marketing, that the mussel industry underwent major expansion. Major steps in progress were the development of specialized spat collecting methods and the evolution and availability of separate growing and harvesting specialties, so that one operator no longer had to be responsible for the entire process. Some degree of standardization and specialization will certainly be necessary in the paua industry, but it is too early to see exactly what form this will take in New Zealand.

Paua farms in New Zealand

Most paua farming ventures in New Zealand are in an early stage of development. The geographic spread encompasses the length of the country from Auckland in the north to Stewart Island in the far south (Table 3A). Most farms are in the cooler waters from Taranaki (west coast, North Island) south. The most common system being used is the V-tank, although there is a wide range of types, with two operations still in the early planning stages (Table 3B). Seven farms will use *Haliotis iris*, one *H. australis*, and one both species (Table 3C). The products will be cocktail-sized paua and mabe pearls.

Husbandry and system interactions

Several models of husbandry and systems are being developed throughout the country. This diversity may be necessary because of regional differences in water temperatures, particularly with the significantly warmer water in northern New Zealand (monthly averages between c. 12 and 21°C) and site-specific differences in water quality and access, even within regions. There is considerable debate about which combination of traits, species and systems is best suited to any given operation. There is also the suspicion that in many cases the sites for paua farming are chosen more for convenience or prior land ownership, rather than for the quality of the site for paua farming.

In southern New Zealand, heating the water during the coldest winter months could result in increased growth of meat and shell, although there is no published information to gauge this relative to costs. If water heating is used, heat pumps will be required and a re-circulating water system that provides constant temperatures to all tanks will be necessary. Also needed will be a filtration system to remove major wastes and a bio-filter system to maintain water quality. Such an integrated system has yet to be tested on a commercial scale. It will also require the use of food that will not clog filters; the break-down of artificial foods can cause problems with this. Size-specific stocking densities will have to be worked out, and the entire system will have to permit easy removal of faeces, food wastes, and paua. Few of these have been subjected to direct research in New Zealand.

An ancillary problem relating to paua aquaculture is the provision of juvenile stock. It seems clear that specialized hatcheries will need to be developed to provide small paua (5–10mm) to other operations. The current price (October 1996) for juveniles ranges from 1.4 to 4 cents per mm, but it is felt that for profitability in an on-growth facility, NZ$0.02 per mm may be the maximum affordable for commercial viability (R. Beattie, NZ Abalone Farmer's Association, pers. comm.).

One problem at this stage is that there is not enough volume of production to keep the price of juveniles low, and with new operators being hesitant to buy paua at a higher price, the demand for juveniles is not steady or high enough to produce economy of scale.

The problem of stock provision is more problematic if pearls are to be produced. The minimum implant size of paua will be *c.*75mm, or 2–3 years old. With the minimum legal size for the natural fishery at 125mm, it is not clear where the volume of appropriately sized paua will come from for a commercial venture in paua pearls.

Provision of food

The nutritional requirements of paua are largely unknown and the quality and use of particular foods will be influenced by the paua species, temperature, production of wastes and the stocking density of paua in particular systems. The provision of quality food that is also economically viable is an on-going concern in New Zealand, as it is elsewhere (Fleming *et al.* 1996). For artificial foods, the best formulation for fast growth, efficient conversion, meat quality, taste and nacre production is still being developed.

The amount of food required by a commercial-scale facility will depend on stocking densities, sizes of paua, water temperature and duration of feeding by paua. "Daily intake" expressed as % Body Weight consumed per day averages *c.* 4% for 7–20mm abalone at 18–22°C and *c.* 1.1% for 25–50mm abalone (from Table 6, Fleming *et al.* 1996). However, there may be considerable wastage from uneaten food and decomposition, and the overall amount of food added to a tank (the "ration") to maximize growth rate may be double the daily intake value (Uki *et al.* 1985, quoted in Fleming *et al.* 1996). With the cost of artificial food presently high (an average of *c.*NZ$4.50 per kg; Table 1, Fleming *et al.* 1996), the economics of meat production of paua are currently unsatisfactory. Of course, this may change with continued improvements in growth rates, conversion ratios, reduced wastes, and reduced food costs, but there is clearly a long way to go for demonstrable economic viability using artificial food alone.

If natural seaweeds are to be used it is not certain which species are best, if permits to harvest them will be granted, and how much will be needed. A commercial facility clearly will require hundreds of tonnes per year, but the source of suitable seaweeds relative to the location of farms, the costs of collection and transport are mostly unknown, yet crucial to the planning necessary in a commercial operation.

Research scale and experimental designs

If research is to aid the development of industry, the science will have to be of a high standard and at a scale appropriate for transferral to commercial use. Searcy-Bernal (1994) presented a timely reminder that not only are rigorous experimental designs testing specific hypotheses necessary in aquaculture, but also that some measure of the power of a test to detect an effect should be determined before non-significant results are interpreted. He illustrated his points by citing an example from his own research (Searcy-Bernal *et al.* 1992) in which the effects of benthic diatoms, abalone mucus and GABA on settlement and survival of larvae were tested. Using Analysis of Variance a significant effect was detected at settlement, but the difference among treatments was not significant after 22 days, even though GABA produced an average of 2.6 times increase in survival over the least effective treatment (diatoms). Two major points are germane: that the statistical power of the test to detect an effect was only 19%, and that accepting the null hypothesis of no treatment effect would discourage the use of GABA, even though it might produce significant improvements in commercial operations. About a third of the papers in Searcy-Bernal's (1994) review interpreted a non-significant null hypothesis as if it were true, and no papers reported the statistical power.

Much research in aquaculture is done on relatively small scales over short time periods. However, this may not be particularly useful to an industry with large facilities within which paua need to be grown for two to three years. An illustrative example from New Zealand research is a feeding study comparing growth of small paua (15 – 25mm) on four algal diets (Stuart and Brown 1994). A recirculating system with a total volume of 250 litres was used, with 5.2 litre glass jars used to hold treatments. There were four algal treatments, each containing three replicate jars with 40 paua. The experiment measured growth rates over 8 weeks when the water temperature was 15°C. *Gracilaria* produced growth rates of 9.7 ± 6.1 mg per day ($\bar{x}$ ± SE), *Macrocystis* 5.9 ± 3.3, *Ulva* 0.8 ± 2.1, and a mixed algal diet 11.6 ± 8.1. Using Covariance Analysis (comparisons of the different diets over time), they concluded that *Gracilaria* and mixed algae produced significantly greater growth rates than the other two treatments. Three points are relevant in applying this type of experiment to commercial use. 1) The experimental scale is so small that results may not translate to the much larger systems used in commercial culture. The spacing of paua, aeration, water flow, and effects of wastes are likely to interact in a different way in a large system. 2) No F-values were given in the experiment (only p-values were cited) and the variation due to separate jars within treatments was not separated from individual paua variation with treatments. The assumption is, therefore, that there was no between-jar within-treatment variation. These omissions combine to make it difficult to assess the power of the test used to detect effects. Because the individual variation within treatments was so high (standard deviations ranged from 22.9 to 88.4) and there were relatively small differences among three of the treatments, the power of the test to detect effects was probably low. In this case, this did not lead to a Type II error because the result was significant. 3) The treatments lasted for only eight weeks. Because of this short time span, compounded with the great variation in growth within treatments, the results may not be particularly helpful for a commercial operation.

A recurring lesson is that aquaculture researchers must continually grapple with high within-treatment variability among individual paua combined with relatively small effect sizes. There are usually logistic constraints on the number of treatments and replication possible, all of which combine to yield generally low statistical power in the critical tests. This may be especially serious where percent survival is the variable being measured. In this case, there is no within-replicate variation (as is the case where several paua are measured for growth within replicate containers) and, therefore, there is a need for greater replication of containers within treatments to achieve a reasonable level of statistical power.

The role of the market

Because the aim of aquaculture is to make a profit, the combination of production system traits, growth of paua, and relevant research will affect the ability to attract investors. Not only will commercial facilities be increasingly driven by market forces, centred on identifiable and branded products, but there will be increasing pressure on scientists to interact with industry to solve problems. A major challenge to scientists, at least in New Zealand, is to demonstrate the relevance of research and science to the aquaculture industry through high quality research that leads to real commercial applications.

What can research accomplish?

I see the major categories needing research attention for the advancement of paua culture in New Zealand as: overall system development and integration, including the interaction with foods; food development both for recently-settled and later stages of paua to achieve better survival, greater growth rates and lower variability; algal harvesting effects and techniques, to provide the information necessary for more permits to be granted and for gauging the relative costs and benefits of artificial vs natural foods; and perhaps a better understanding of the genetics affecting meat quality and colour, growth rates, and shell colour.

Overall, despite the current progress of the paua culture industry in New Zealand, there is good reason to be cautious in optimism. Many places worldwide are further developed in abalone aquaculture, and wild stocks of paua are still reasonably plentiful, so there will have to be very good marketing to sell products and keep prices up to meet the expectations of investors. Some successful niche markets are likely to arise, and progress in the production and marketing of paua pearls may prove to be the greatest success. However, history to date encourages me to wait and see, rather than to predict a clear road ahead.

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